2003 DOE Wire Workshop Summary

Perspectives, Issues, and Goals

Terry Holesinger (LANL)
Parans Parathaman (ORNL)
Steve Dorris (ANL)

A note from the organizers:

Our gratitude goes out to all the people who were involved in session planning and presentations, and to Jim Daley, whose leadership has made this program the success it is today. We hope that this workshop serves as an impetus for significant progress in Coated Conductor Technolgoy before the 2004 DOE Wire Workshop.

Introduction

This presentation is a summary of the 2003 DOE Wire Development Workshop held in St. Petersburg, FL on January 21 and 22. The goal of the workshop was to identify key issues or problematic areas in scaling-up coated conductors to commercial lengths and in developing applications related to generators, motors, or transmission cables. A key feature of the workshop was the central role of industry representatives in planning the sessions and participating in panel discussions. The presentations given during the two-day workshop illustrated the tremendous amount of progress the program has made in transforming Coated Conductors from laboratory curiosities into real-world conductors. Individual sessions dealt with the production of textured templates, buffer layer development, $YBa_2Cu_3O_y$ (YBCO) deposition processes and properties, application development, characterization for programmatic needs and structure / processing / properties relationships, late-breaking news items, and University involvement in the field of Coated Conductors. Key excerpts from the talks have been included in this summary. Persons wishing to find out more about individual talks should contact the presenting authors directly.

Notes

1G - First generation wire, powder-in-tube Bi-2223

2G - Second generation wire, RE-123 Coated Conductor

2003 DOE Wire Workshop Program

Tuesday, January 21

- Session I: Update on activities in Europe, Japan, and U.S. Industries
- Session II: Textured Templates
- Session III: Buffer Layers
- Session IV: YBCO Deposition
- Session V: Late Breaking News

Tuesday Night

- Session VI: Rump Session: Application and Conductor Development

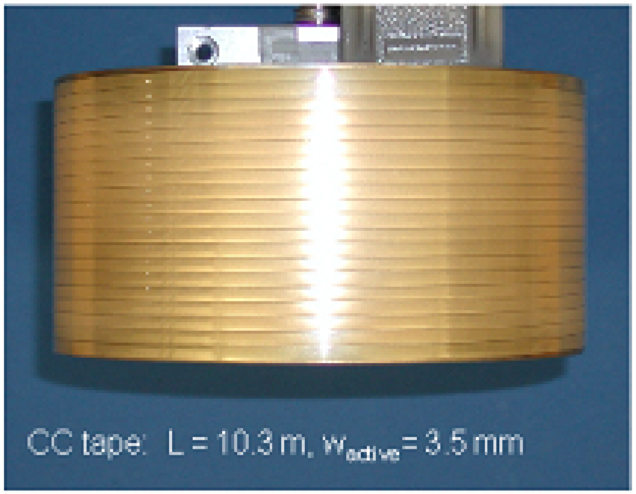
Wednesday, January 23

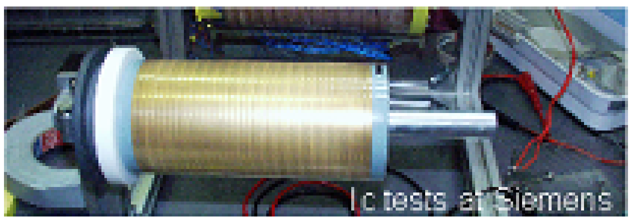
- Session VII: Characterization
- Session VIII: Role of Universities

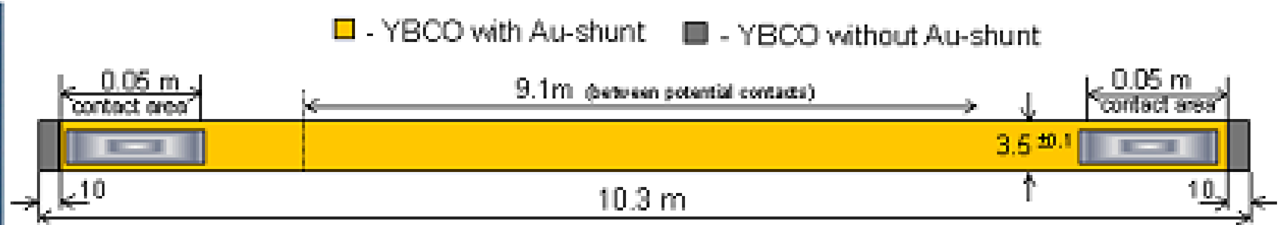
Foreign Efforts in HTS Coated Conductors

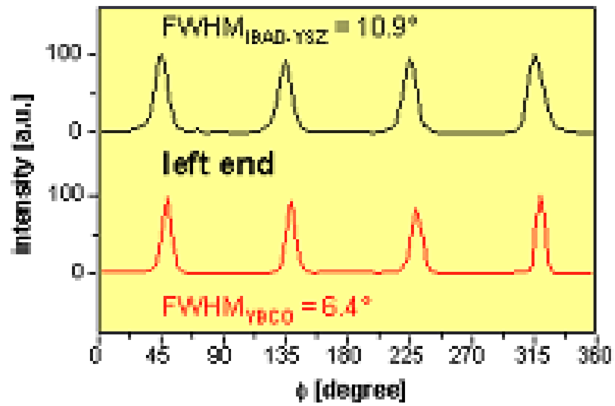
- **Robust funding in Japan;**
- **German funding is uncertain**
- **Recent Göttingen results set current Coated Conductor Benchmarks**
  - **1 m - 1.3 MA/cm^2 / 317 A/cm**
  - **10 m - 2.2 MA/cm^2 / 223 A/cm**
  - **20 cm - J_c(?) / 391 A/cm**
- **University of Augsburg**
  - **Ca-doping for improved grain boundary properties**
  - **Successfully applied to RABITS / IBAD YSZ samples**
- **Stabilization, Non-magnetic substrates**

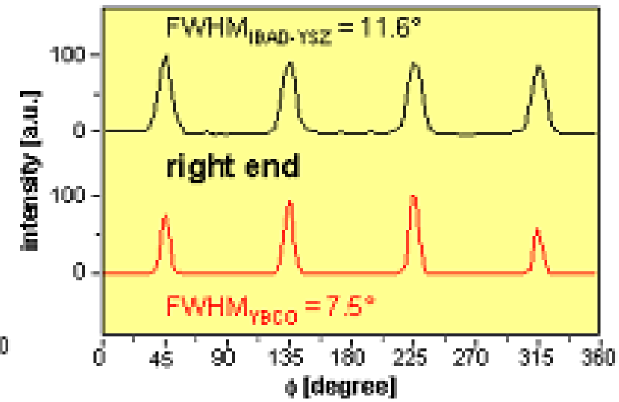
European Highlight - Univ. Göttingen/ZFW











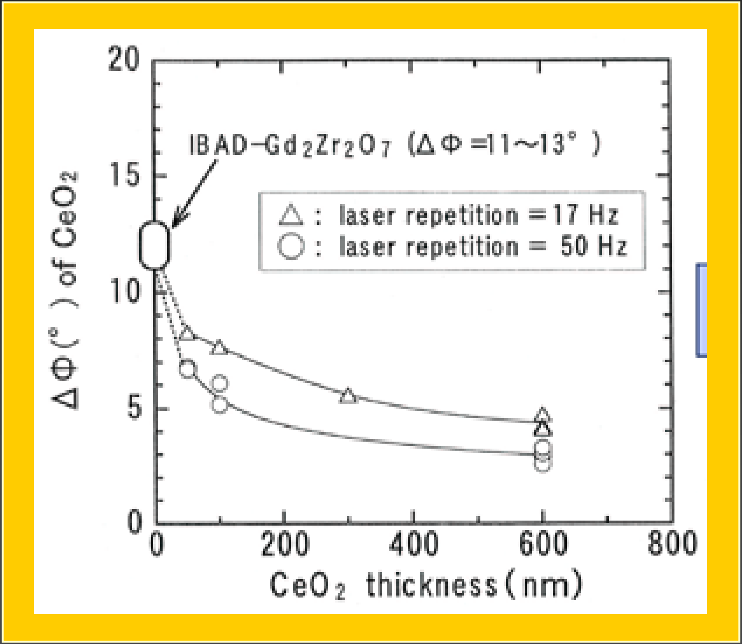
- SS tape (0.1 mm) // IBAD-YSZ (1.3 µm) // CeO_2 (<0.1 µm) // YBCO (1.0 µm)
- Coated Conductor : **10 m long, 4 mm wide, with 3.5 mm wide YBCO film**
- Critical current, I_c, and current density J_c :

I_c = 78 A & J_c = 2.23 MA/cm^2 , & Ic/w = 223 A/cm (77K, SF)

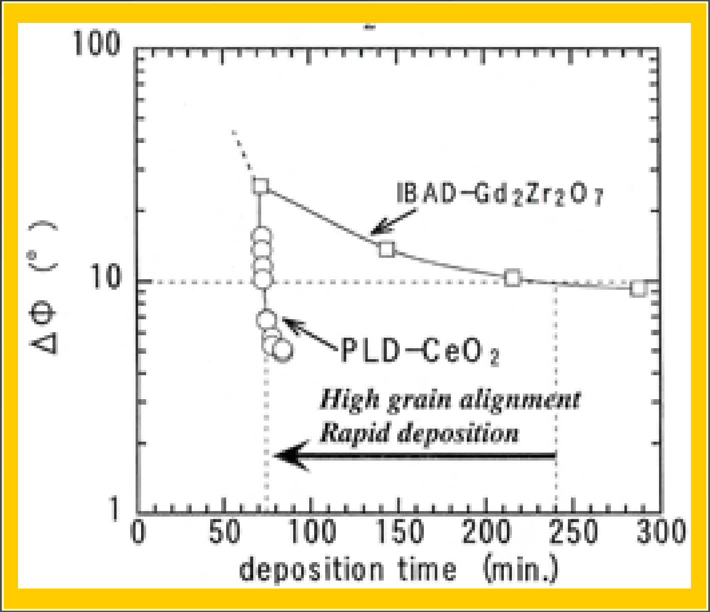
A.Usoskin\2002\ASC'02\10m 66A_4.ppt

Japan Highlights

- **Faster and improved texture development with a combination of IBAD $Gd_2Zr_2O_7$ (GZO) and PLD Ceria**
- **High current (210 A) coated conductors with IBAD GZO (1 µm) / PLD CeO_2 (0.5 µm) / TFA YBCO (1.4 µm)**



Fujikura / ISTEC-SRL - Self-epitaxy in CeO_2 on IBAD GZO found to lower in-plane texture to values below 5˚ in a shorter amount of time.



Japan Highlights - IBAD and ISD Long Lengths

- **IBAD-based coated conductor: 46 m length with end-to-end J_c(77K, SF) of 0.5 MA/cm^2 (I_c = 74 A)**
- **Demonstrate long length production with 100 m of IBAD GZO (t = 1.2µm, rate = 0.5 m/hr) template with $\Delta\phi = 10^\circ$.**
- **ISD-based coated conductor: 50 m length with an end-to-end J_c(77K, SF) of 0.15 MA/cm^2 (HoBCO for active layer, I_c = 15 A)**
- **Goals for next stage (5 years) of research**
  - ✓ **500m coated conductor piece-lengths**
  - ✓ **Cost of $100/kA-m**
  - ✓ **Performance 300A/cm width**
  - ✓ **Production rate of 5 m/hr**

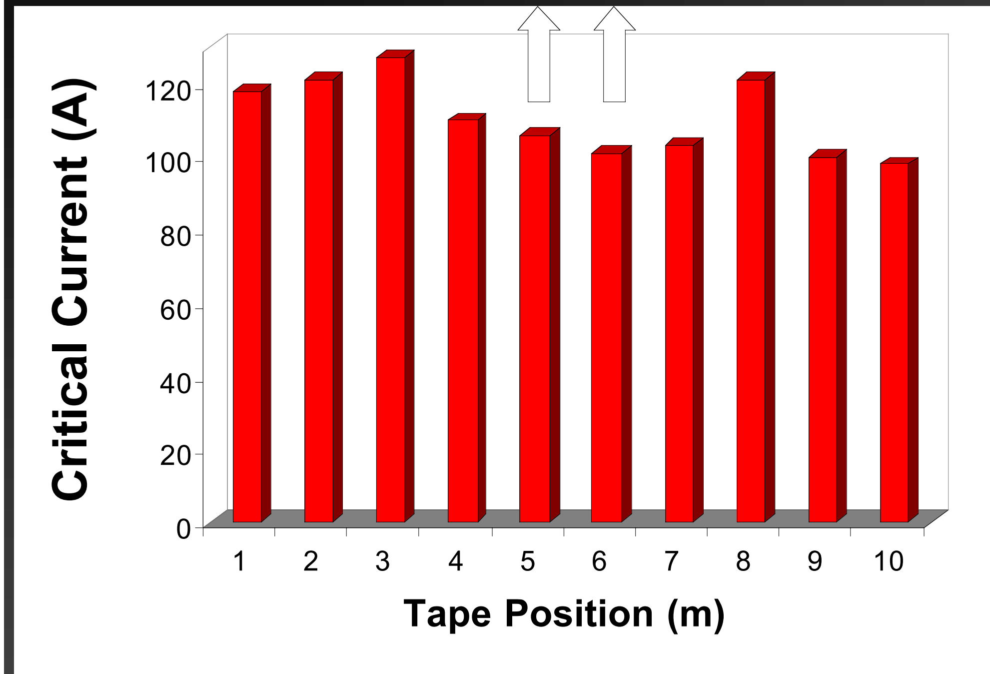
U.S. Industry Perspectives

- **Current Status - Process reliability prior to pilot scale production**
  - ✓ **Multi 1-meter results for reproducibility studies**
  - ✓ **Establish baseline R&D expectations for scaleup**
  - ✓ **Developing specifications for equipment scaleup**
  - ✓ **Form-fit-function replacement for First Generation (1G) conductors (AMSC viewpoint)**
  - ✓ **Advanced application development with 1G conductors which are available now in commercial lengths.**
- **High J_c / I_c demonstrations; Long length processing of Coated Conductors**
  - ✓ **ASC**
  - ✓ **SuperPower**
  - ✓ **Oxford / MCT**

Progress at SuperPower

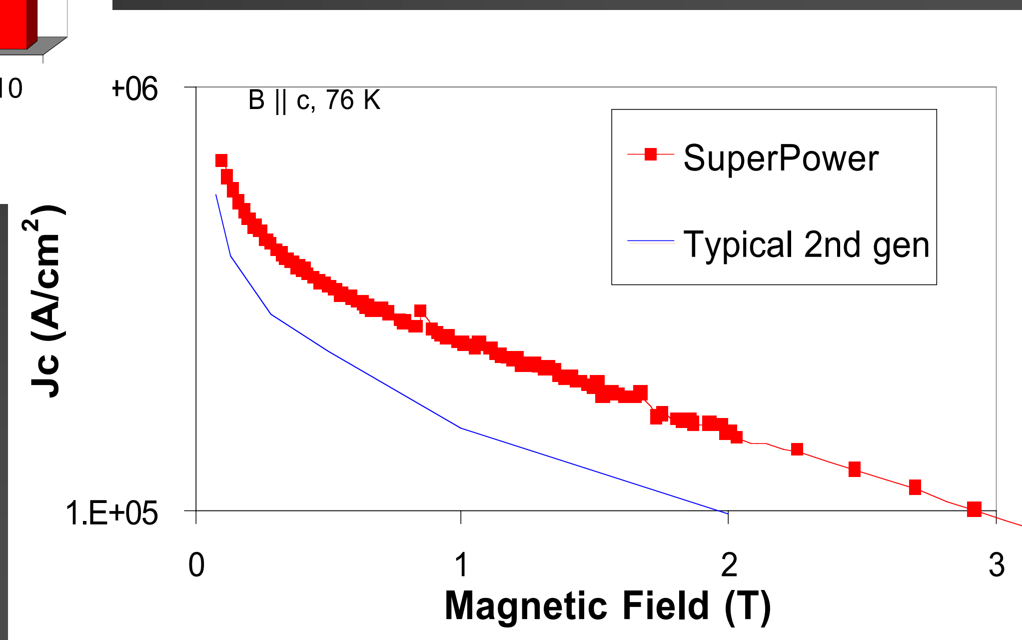
- **Main work at present on IBAD with PLD or MOCVD YBCO**
- **Aiming for high-rate, large area deposition process for YBCO**
- **Good progress towards long lengths**
  - **10 m / 106 A (Individual 1m-sections substantially higher)**
- **Improved performance from MOCVD films**
  - **1 cm - 205 A**
  - **1 m - 173 A**
  - **Improved in-field performance (factor of 2 compared to other G2 tapes)**
- **Albany Cable SPI**
  - **34.5 kV, 1/4 mile standard underground right-of-way deployment**
  - **30m section to be based on Coated Conductor**

Key Highlights - SuperPower



106 A over 10 m of an IBAD-based Coated Conductor; individual sections were substantially higher.

Substantially improved in-field performance of a YBCO CC by a factor of two.

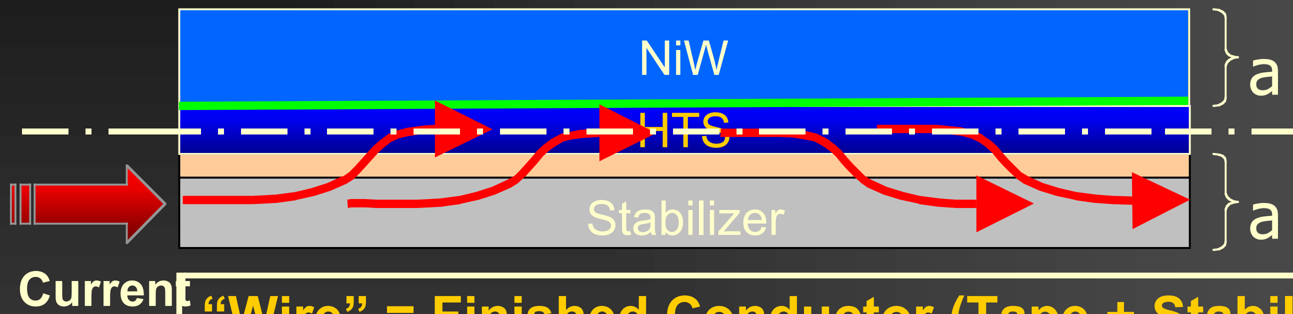


Progress at American Superconductor

- Addressing a "form-fit-function" replacement for BSCCO
- Active development of Transmission Cables, Motors, Generators, and Separation / Specialty Magnets with 1G wire
- 900 km/yr production of 1G wire
- Commercial 2G wire possible (200 km) within 2-3 years
- Main development of 2G wire is with RABiTS
  - ✓ 100 A/cm @ 10m
  - ✓ 132 A/cm @ 7m
  - ✓ 200 A/cm @ 1cm (Both RABITS and IBAD MgO)
  - ✓ Good mechanical properties
- Emphasized development of the conductor
  - ✓ Stabilizer + 2G tape
  - ✓ Design
  - ✓ Wire handling processes
- 2G volume manufacturing from processing wide tapes and slitting.

Highlights - American Superconductor

- 100 A over 10 m of RABiTS - based Coated Conductor
- "Neutral Axis" Conductor Design = "Wire"



"Wire" = Finished Conductor (Tape + Stabilizer +)

- World's first commercial HTS (1G) wire plant now in operation

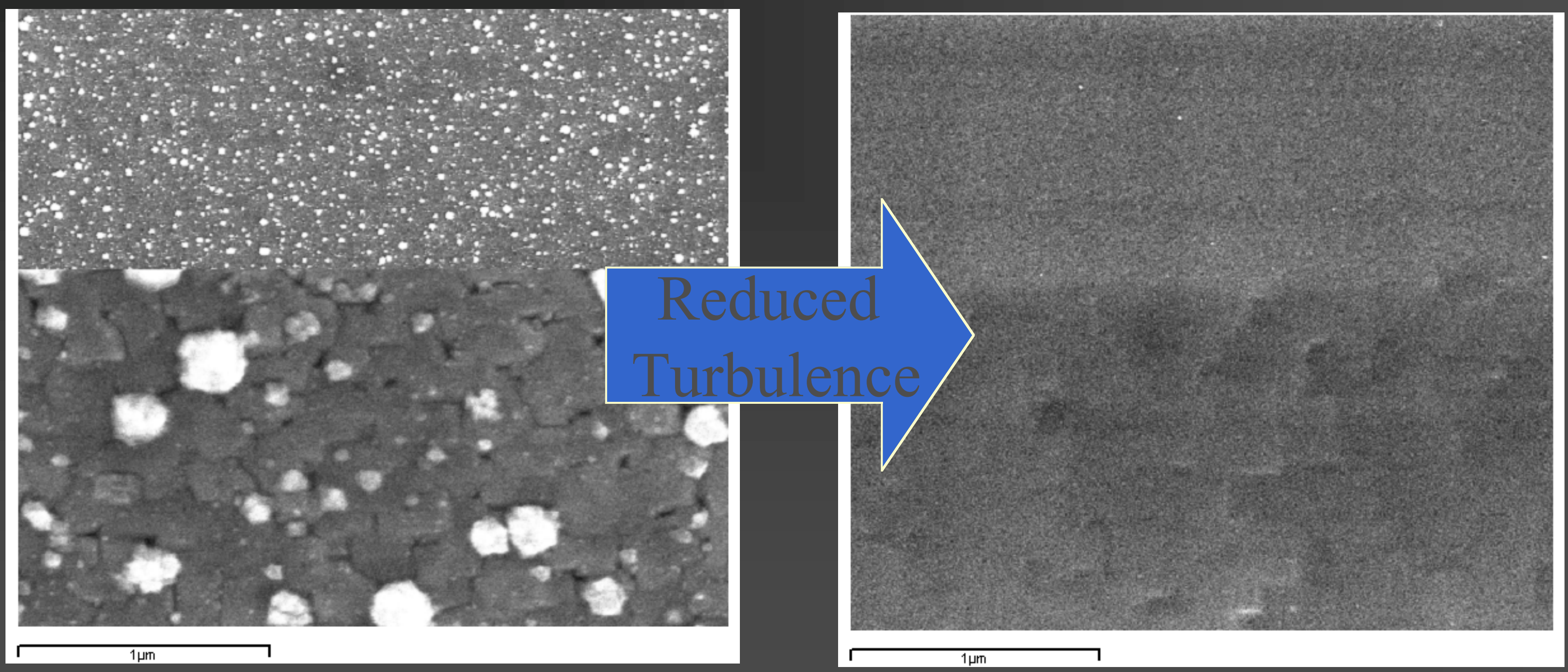
900 km/yr of 1G wire with room for additional capacity.

Progress at MCT / Oxford

- RABiTS for commercial production
  - Surface roughness
  - % cube texture
  - 100 m piece lengths
- Pursuing CCVD processing for low-cost, non-vacuum deposition of buffer layers and YBCO.
- Demonstrated high J_c (1.12MA/cm^2) via PLD YBCO on CCVD buffered RABiTS.
- Set aggressive 2003 goals for 25 m piece lengths of fully-buffered CCVD RABiTS for high I_c conductors.
- Continue the sale of CCVD buffered tapes.

Highlights - MCT / Oxford

- **Process optimization for improved buffer layer characteristics via the CCVD process.**
  - ✓ **Smoother films**
  - ✓ **Less particulate**

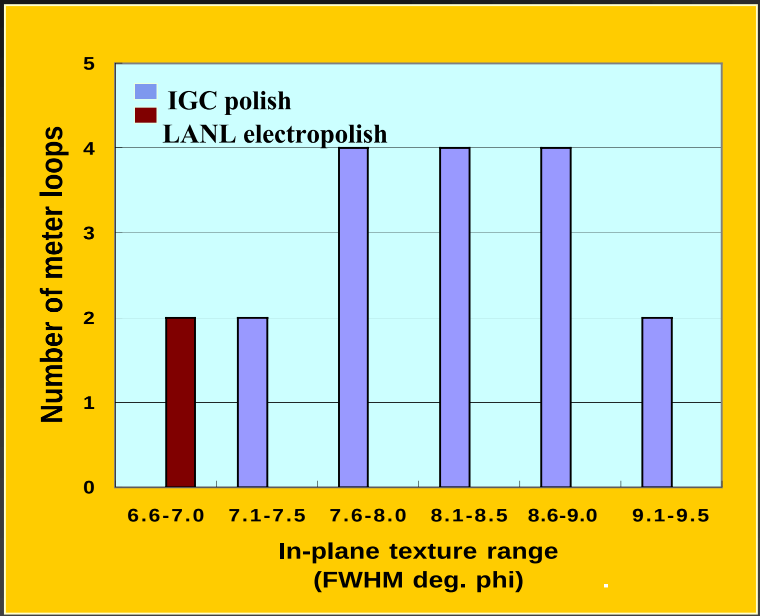


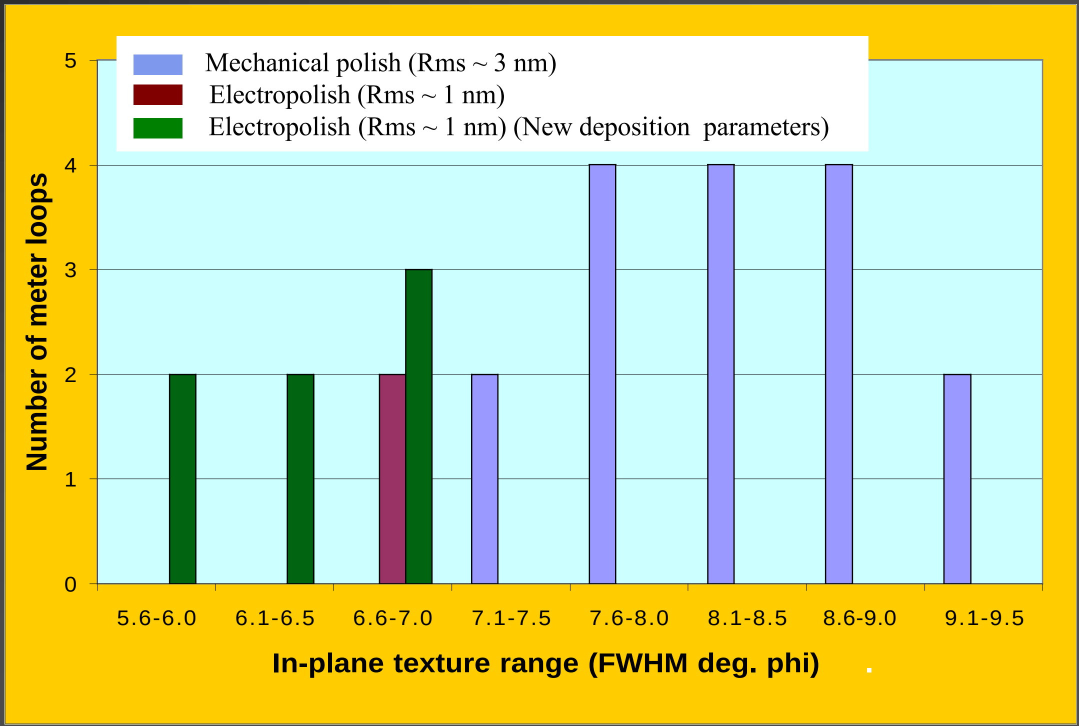
Session II: Textured Templates - Paul Arendt (LANL)

- **IBAD MgO Development**
  - ✓ Commercial viability
    - Commercially available substrates
    - Industry proven processes (electropolishing) for substrate preparation
  - ✓ Processing speeds improving
    - Current length potential - 5m/hr @ 0.1 nm/sec (Los Alamos Research Park)
    - Pilot Scale line: 10cm x 60cm deposition zone ➝ 250 m/hr @ 0.1 nm/s ➝ 6km / 24 hr day or ≈ 2000 km/y
    - Comparable texture with deposition rates of 0.2-0.3 nm/s
  - ✓ Process reliability
    - Texture improvement was achieved with process optimization
    - Achieved FWHM < 5˚ in-plane
    - Goal is to routinely achieve <5˚ texture for process reliability

Textured Templates - Paul Arendt (LANL)

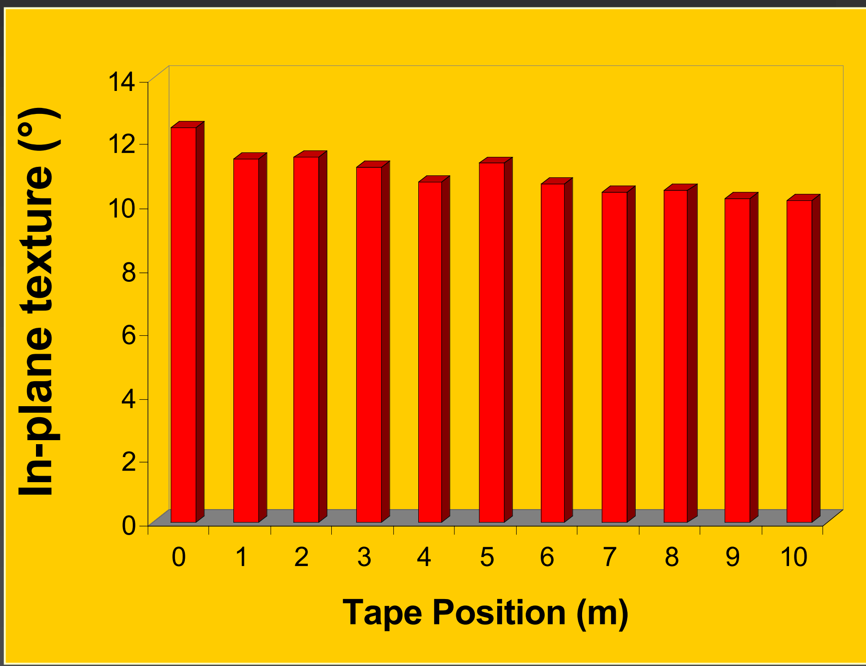
- **Steady progress towards better texture, higher reproducibility**

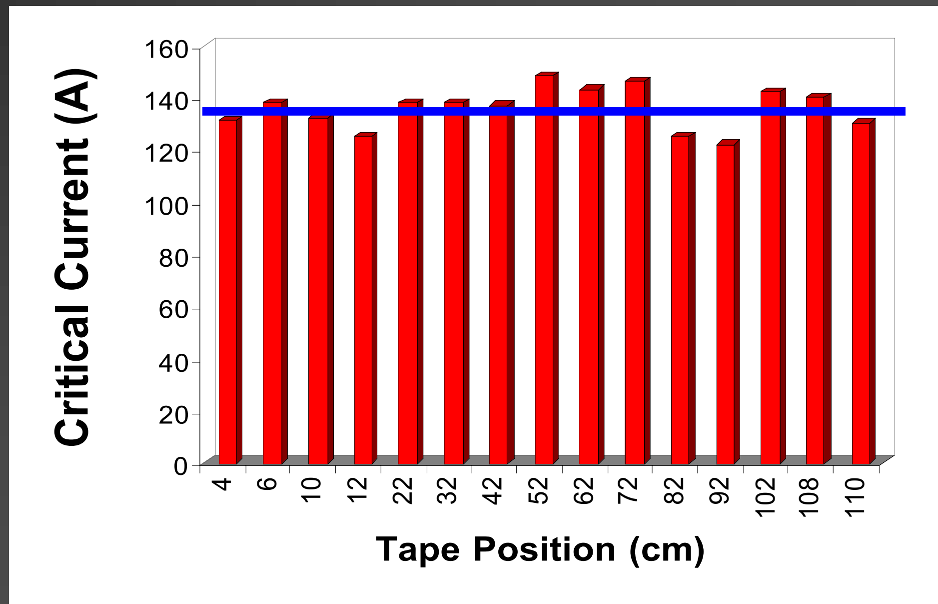




Textured Templates - SuperPower

- Emphasis is on establishing
  - ✓ improved substrate manufacturing processes,
  - ✓ reel-to-reel on-line & off-line QC tools
  - ✓ equipment with increased yield for long length
- Uniform IBAD texture over 10 m
- Elimination of edge delamination problem increased current capacity



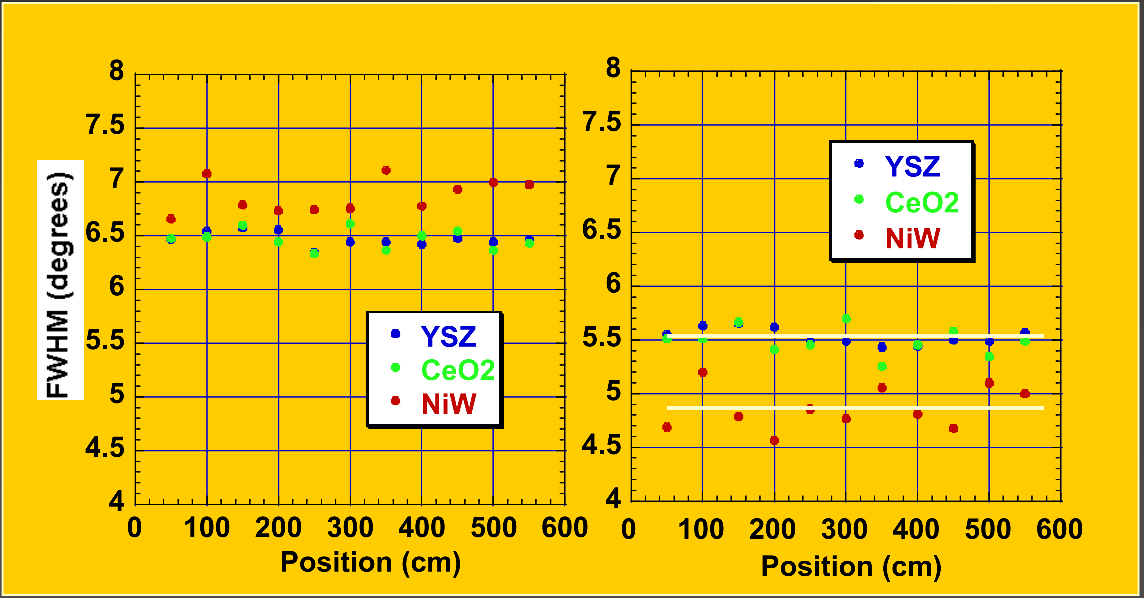


Textured Templates - Amit Goyal (ORNL)

- **Standard RABiTS tape**
  - ✓ **Ni-3%W (50µm) / Ni (1µm) / Y_2O_3 (20nm) / YSZ (200 nm) / CeO_2 (20nm)**
  - ✓ **Buffer layers added vie PVD methods**
- **Important to define the true in-plane FWHM**

$$\Delta\Phi_{\text{true}} = \sqrt{\Delta\phi^2_{\text{observed}} - \tan^2\chi\left(\Delta\omega^2_{\phi=0}\cos^2\phi - \Delta\omega^2_{\phi=90}\sin^2\phi\right)}$$

- **Improve out-of-plane texture for better GB properties.**
- **Working on reduced magnetism and non-magnetic substrates (Cu).**



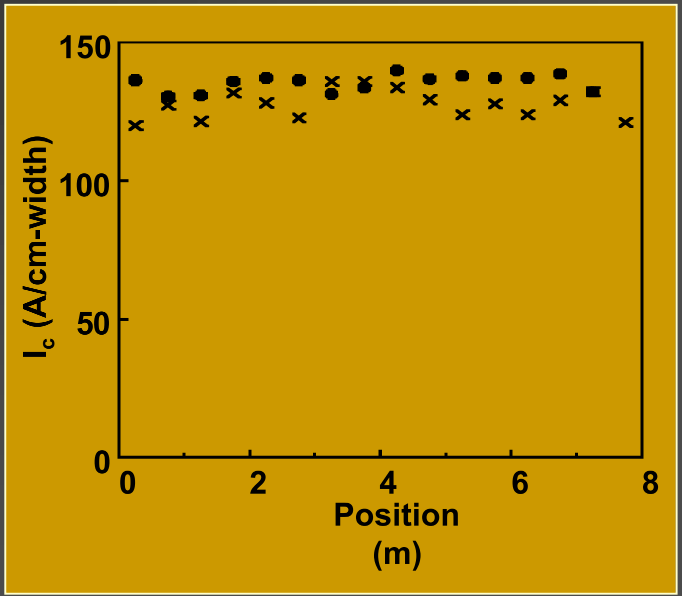
Texture results in right hand plot are the calculated true in-plane texture values using the data from left hand plot of the measured (111) phi scans.

Textured Templates - Ken Marken (Oxford)

- **All manufacturing steps have been demonstrated for 100 m piece lengths; scale-up to 1 km lengths should be feasible**
- **1 MA/cm^2 YBCO values obtain via several different coating methods.**
- **Rate limiting step is currently the strip anneal (15 cm/min)**
- **Biggest influence on texture is the starting material**
  - ✓ **Don't understand grain size effects in starting ingots**
  - ✓ **Don't understand chemistry (trace metal) effects in starting material**
  - ✓ **Yields are currently low due to these issues**
- **Secondary recrystallization remains poorly understood.**

Textured Templates - Marty Rupich (AMSC)

- Consistent texture in RABiTS wires and uniform critical currents over long lengths.
- Process rate definition - Manufacturing efficiency, cost and throughput are determined by the volumetric deposition or growth rate – not simply the simple linear deposition or growth rates.
- Volumetric Process Rate depends on
  - ✓ Deposition (or reaction) area (length x width)
  - ✓ Deposition (or growth) rate (A/sec)
- Scalable, Wide Web Processes Required for Manufacturing
- I_c variations are lower than current models predict.



Textured Templates - Marty Rupich (AMSC)

- **Required Advances in RABiTS™ Processing**
  - **Substrate development and characterization**
    - **Improved texture**
    - **Improved characterization over length**
    - **Correlation of texture with performance**
  - **Buffer development and characterization**
    - **Characterization of oxygen and metal diffusion**
    - **Thinner buffer layers / elimination of buffer layers**

Textured Templates - Beihai Ma (ANL)

- **ISD at ANL - present status**
  - **Proven Attributes of ISD**
    - **Good texture at high speed (20-100 Å/sec; FWHM ≈ 10˚)**
    - **Substrate independent texture (roughness 2-30 nm)**
    - **Scale-up potential (35 cm piece-length; FWHM 12-18˚)**
    - **Decreased roughness with homoepitaxial cap layer**
  - **Critical Issues**
    - **Stronger texture, high J_c in HTS**
    - **Effects of roughness**
    - **Improving texture in continuous processing**
    - **Buffer layers / HTS improvements**
  - **Best result**
    - **I_c 10.2 A at 77K, SF**
    - **J_c = 0.55 MA/cm^2**
    - **YBCO t=0.46 µm on a 0.4 x 1 cm sample.**

Textured Template Tie in with Basic Research

- **Methodology for testing FWHM of texture;**
  - ✓ **Absolute amount of texture to achieve high performance. (processing independent)**
  - ✓ **Functional relationship capturing both in-plane and out-of-plane texture.**
  - ✓ **Correlate to grain-boundary J_c's.**
  - ✓ **Bi-crystal work is still relevant.**
- **Characterization of grain boundary and bulk diffusion**
  - ✓ **Methodology for tracking metal / oxygen diffusion from and/or into the substrate. (SIMS?)**
  - ✓ **How effective are the barriers to diffusion / corrosion**

Textured Template Tie in with Basic Research

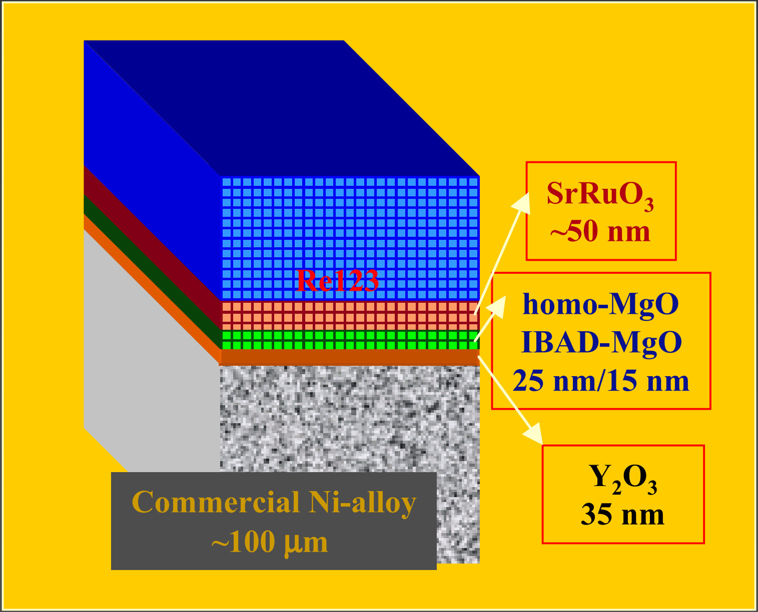
- **Research into better materials**
  - **IBAD - new materials for texturing, substrates**
    - **Stainless steels, other commercial alloys**
    - **Smoothness, low inclusion density, cheap**
  - **All methods - Diffusion barrier / corrosion resistant materials**
  - **RABITS™- Material specifications for starting ingots**
    - **Trace metal effects**
    - **Grain size effects**
  - **RABITS™- Secondary recrystallization**
- **ISD - eliminating buffer layer tilt.**

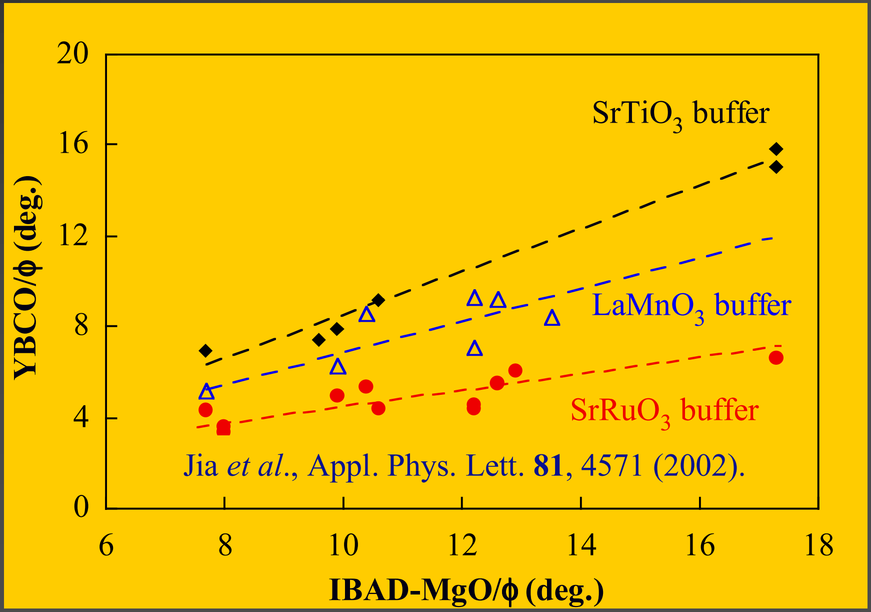
Session III- Buffer Layers

- Choice of buffers is important
  - Substrate match
  - Process compatible
  - YBCO match (structural and chemical)
  - CTE match between layers in composite
- Structural compatibility, thermal stability, chemical stability, barrier diffusion
- Need better characterization of material properties oxygen and metal diffusion. (Corrosion and Diffusion rates)
- Cost can be minimized by making buffer layers as thin as possible (typically < 100 nm)

Buffer Layers - Quanxi Jia (LANL)

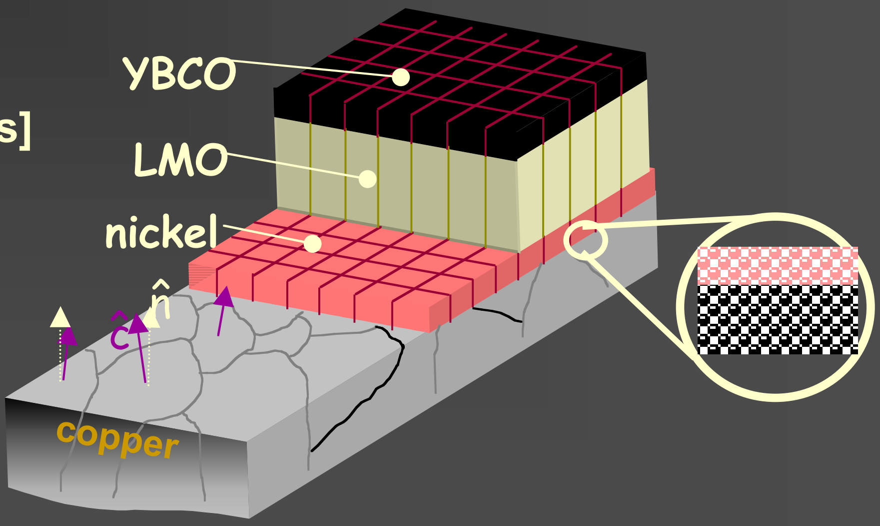
- $SrTiO_3$ (STO) and $SrRuO_3$ (SRO) Buffer Layers on IBAD MgO
  - ✓ Better texture with YBCO on SRO compared to other materials on comparable IBAD MgO templates.
  - ✓ 2.3 MA/cm^2 (320A/cm-width) YBCO (t=1.4 μm) on SRO/MGO(IBAD)
  - ✓ 4.9 MA/cm^2 (230 A/cm-width) with EBCO (t=0.47 μm)
  - ✓ Buffer layers may be able to heal defects that propagate from the substrate
  - ✓ CeO_2 cap layer needed for MOD process – not compatible with SRO
  - ✓ Ru cost is high, but little material used





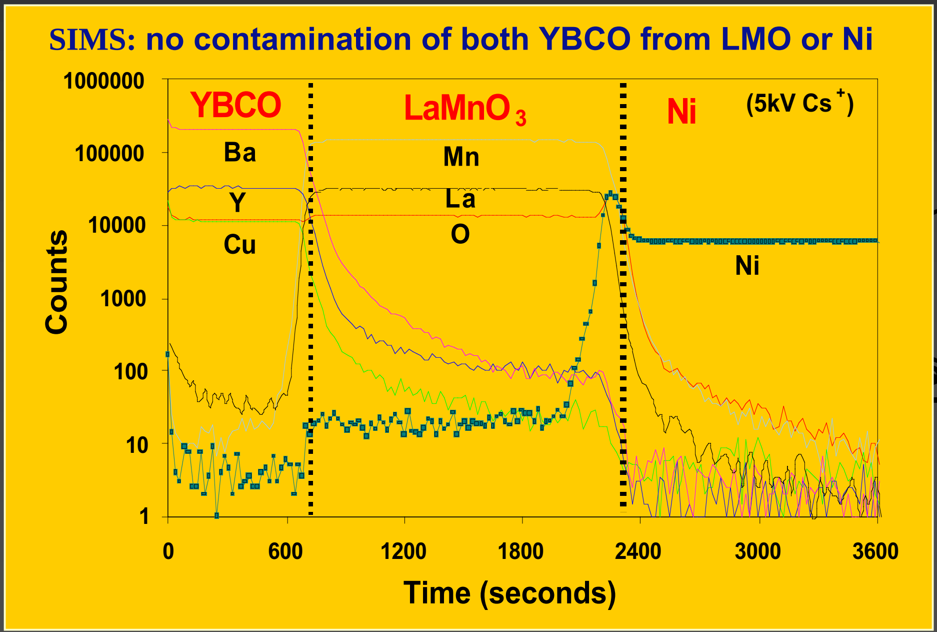
Buffer Layers - Dave Christen (ORNL)

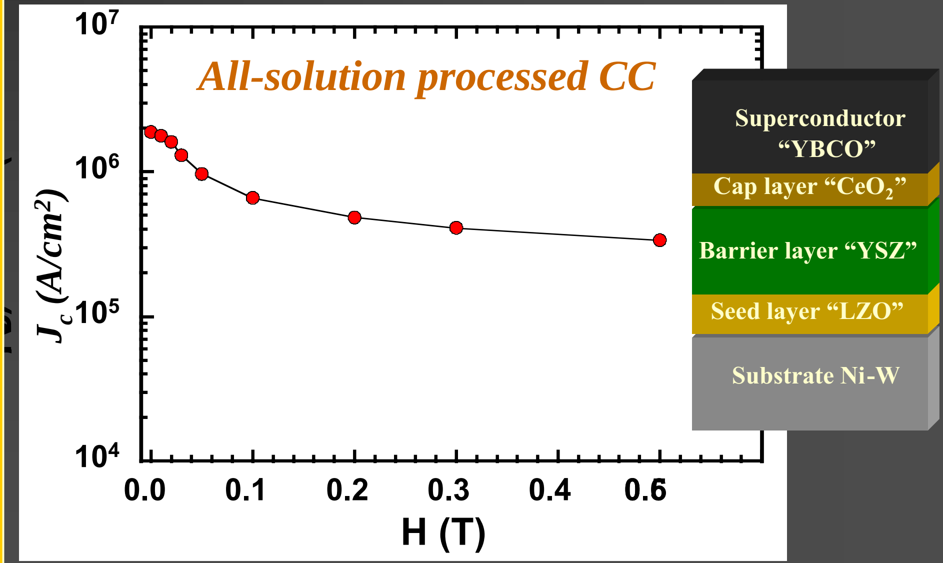
- Buffer layers for Cu substrates
  - Cu substrate – 6x lower cost than Ni
  - With conductive buffer layer, no need for stabilizer
  - Challenges for Cu
    - Rapid copper diffusion through oxide buffer layers [chemical contamination of HTS coating]
    - Rapid formation of Cu-O [related to high Cu diffusivity through native oxides]
    - Low mechanical strength of pure copper [strong alloys and dispersions possible?]
- Large thermal expansion
  - [compressive stresses on HTS coatings]
  - Can use Ni overcoat
    - too much Ni – magnetic
    - too little Ni – oxidation
    - 1 MA/cm^2 with YBCO/LMO/Ni/Cu



Buffer Layers - Parans Paranthaman (ORNL)

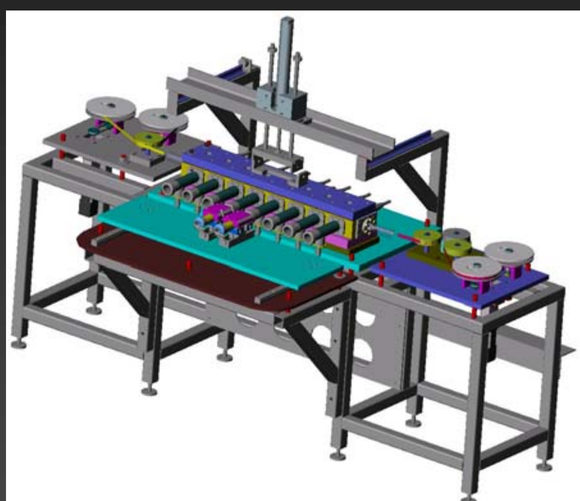
- **Strategic Research in Buffer Layers for Coated Conductors**
  - ✓ $LaMnO_3$ (LMO) and $LaZrO_3$ (LZO) may be good Ni barrier due to La_2NiO_4 formation
  - ✓ $LaMnO_3$ has been identified as an excellent Ni and Cu diffusion barrier layer
  - ✓ Alternative MgO-based RABiTS architecture: CeO_2/LMO/MgO/Ni-alloy
  - ✓ LMO is compatible with IBAD-MgO buffers; High I_c of > 230 A/cm
  - ✓ LZO has also been identified as an excellent Ni diffusion barrier layer
  - ✓ YBCO films (J_c of 2 MA/$cm^{2)}$ on all solution LZO buffered Ni-W substrates



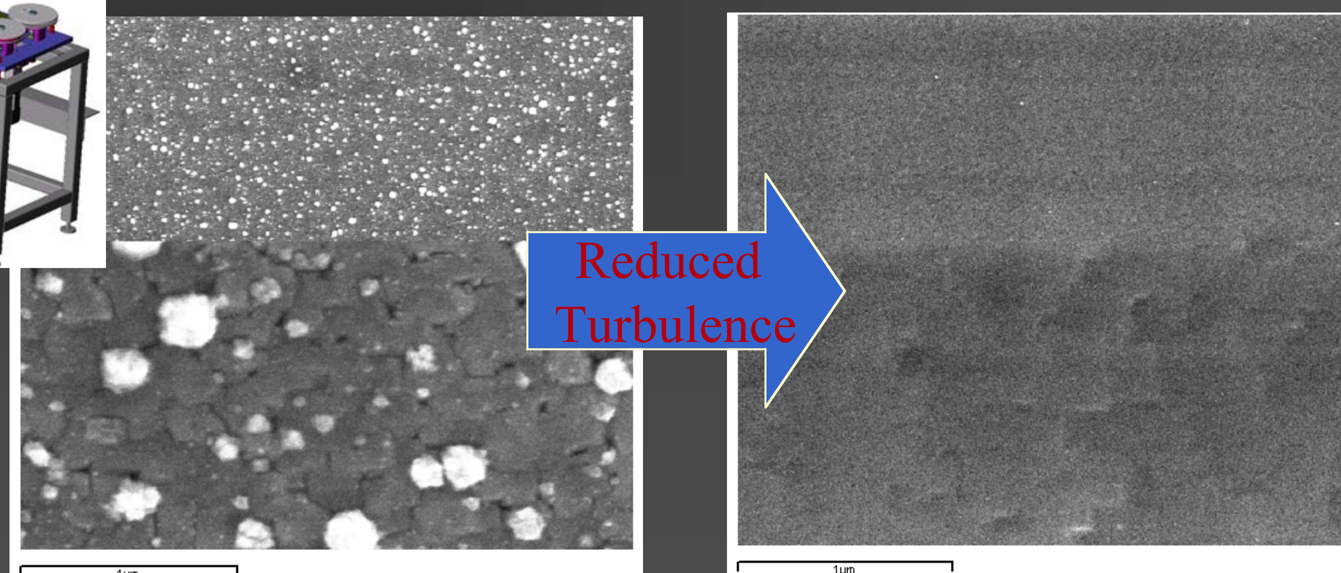


Buffer Layers - Todd Polley (MCT)

- **CCVD (Non-vacuum) Processing of Buffer Layers on RABiTS**
  - ✓ **Buffers deposited on NiW, focused on improved properties and rates**
  - ✓ **Reduction of gas turbulence near deposition region reduces particle formation**
  - ✓ **Smooth, dense STO microstructure and reduced out-of-plane misorientation**



MCT's Scaled 8-nozzle System to be completed by March 2003.



SESSION IV: Thick YBCO Film Growth

- **S. Foltyn (LANL): PLD-101**
  - **Interdependence of pulse energy, target → substrate distance, $p(O_2)$**
  - **J_c vs. thickness still a key issue, (thick film vs thin film characteristics)**
  - **IBAD MgO helped solved thick film problems.**

- **R. Feenstra (ORNL): BaF_2 process**
  - **J_c vs. t effect is substrate independent; J_c in thick films seems to be grain boundary limited.**
  - **Modified precursors and modified processing conditions have led to improvements in thick films.**

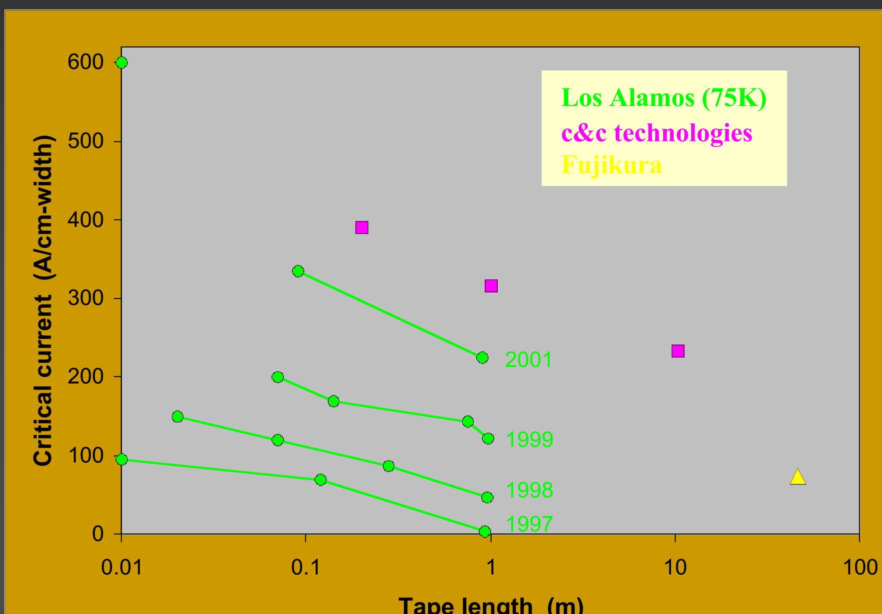
- **M. Rupich (AMSC): MOD processing at AMSC**
  - **1.5 MA/cm^2 for ≈ 1µm YBCO in 1 to 10 m lengths; 10Å/sec deposition rates.**
  - **Steady progress in MOD precursor and process improvements (100% material usage)**
  - **Precursor "decarbonization" in hour (thickness independent)**

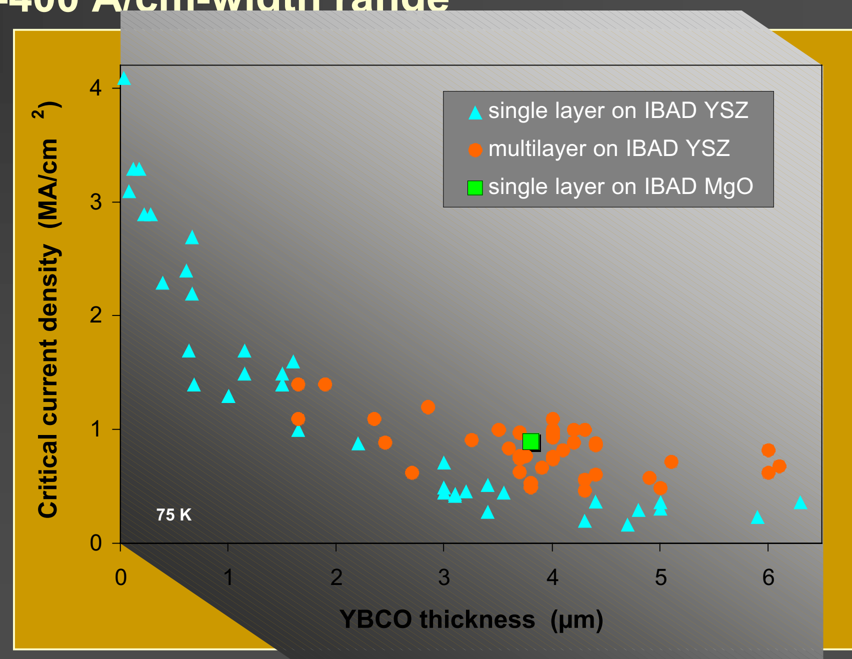
SESSION IV: Thick YBCO Film Growth

- **H.-G. Lee (SuperPower): PLD and MOD at SuperPower**
  - ✓ discussed deposition rate vs. method (PLD>MOCVD>BaF_2>MOD); metric?
  - ✓ I_c vs. in plane texture; also, porosity / roughness issues
- **J. Voight (SNL): MOD at SNL**
  - ✓ MOD of STO (<500OC)
  - ✓ shortening process times / perfecting thick precursor growth
  - ✓ understanding growth processes/mechanisms
- **A. Goyal (ORNL): Thick PLD YBCO on Buffered Ni-3%W**
  - ✓ starting to make thick films that look homogeneous through thickness
  - ✓ intra- and inter-grain J_c vs. film thickness needs to be investigated

YBCO Deposition: Steve Foltyn (LANL)

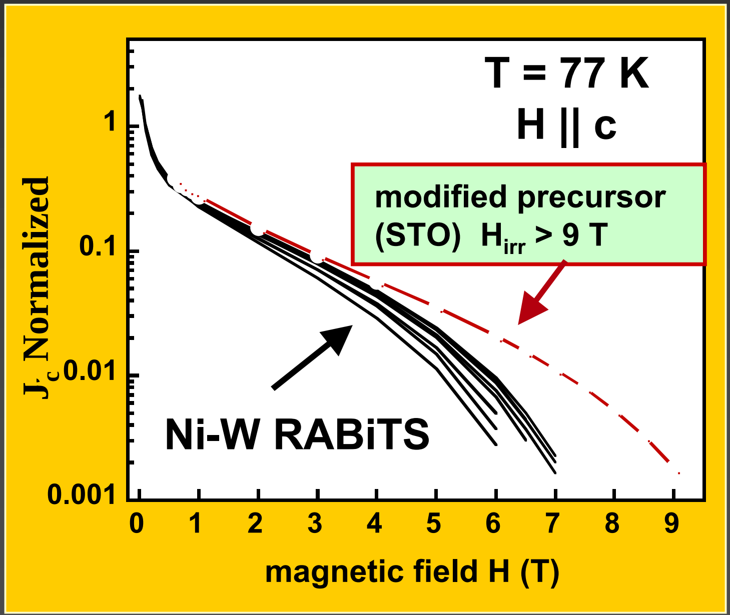
- PLD Coated Conductors have steadily improved year over year.
- Standard YBCO on IBAD MgO is comparable to best multilayer coatings on IBAD YSZ.
- The more interesting -- and economically significant -- issue is improving J_c for thinner films …
  - ✓ IBAD YSZ - 2.3 µm YBCO, 2.7 MA/cm^2, 620 A/cm-width (short sample)
  - ✓ IBAD MgO- 1.35 µm YBCO, 3.0 MA/cm^2, 405 A/cm-width (short sample)
  - ✓ 1m length - 225 A with sections in 300-400 A/cm-width range

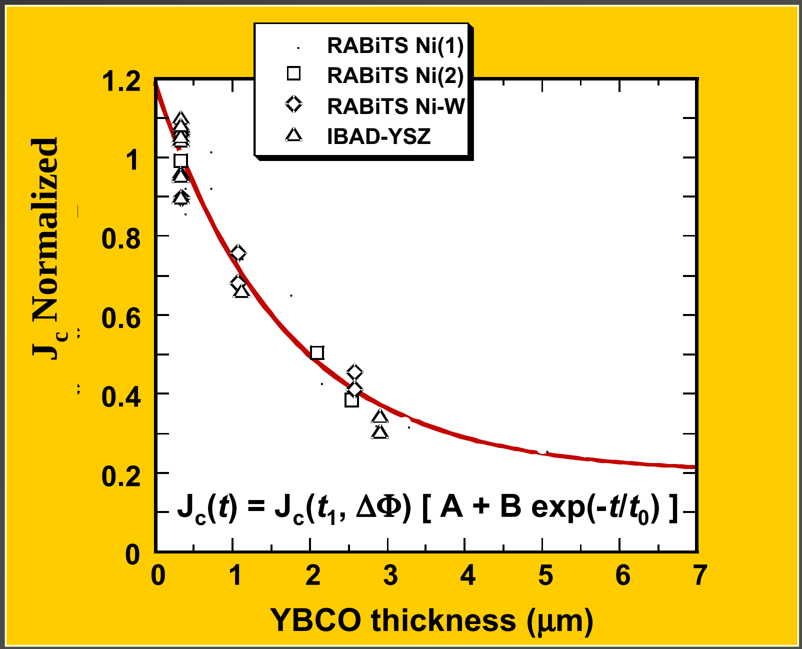




YBCO Deposition: Ron Feenstra (ORNL)

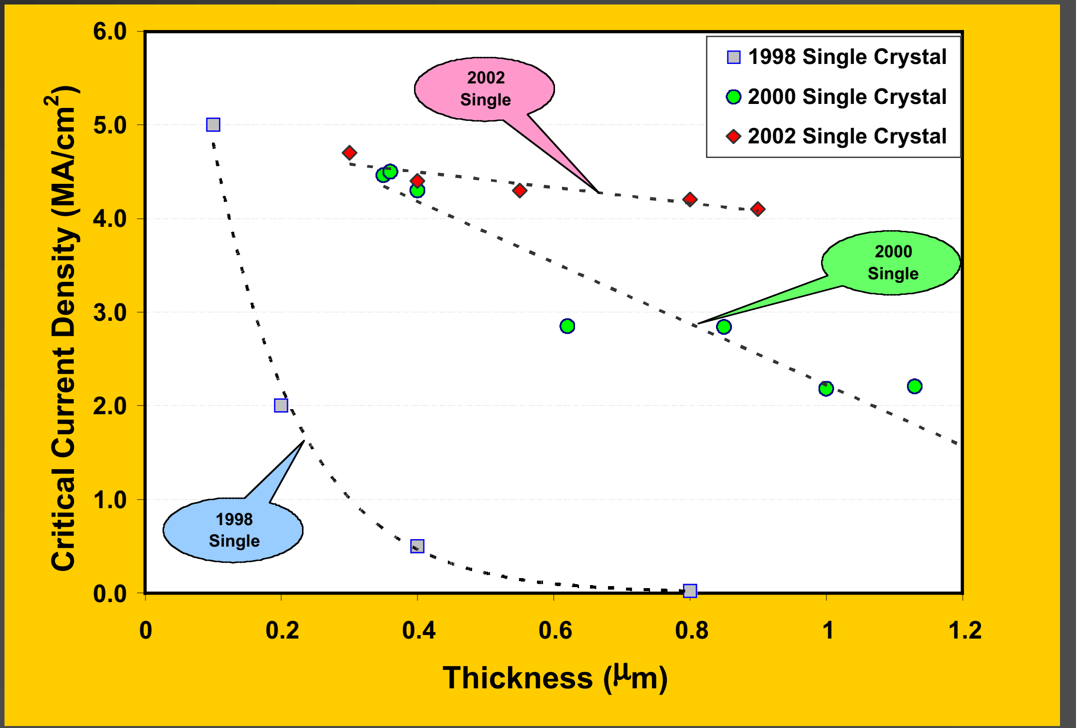
- **Baseline $J_c(t)$ has been determined for BaF_2-based YBCO films.**
  - ✓ Characteristic of current processing / Substrate independent
  - ✓ Dead layers are absent suggesting high I_c films > 3 µm possible.
  - ✓ Imperfect epitaxial growth possible cause of strong $J_c(t)$ dependence.
- **Weaker $J_c(t)$ dependence may result from improved processing.**
  - ✓ Modified process - 235 A/cm-width in a 1.35 µm film.
  - ✓ Improved field performance demonstrated.





YBCO Deposition: Marty Rupich (AMSC)

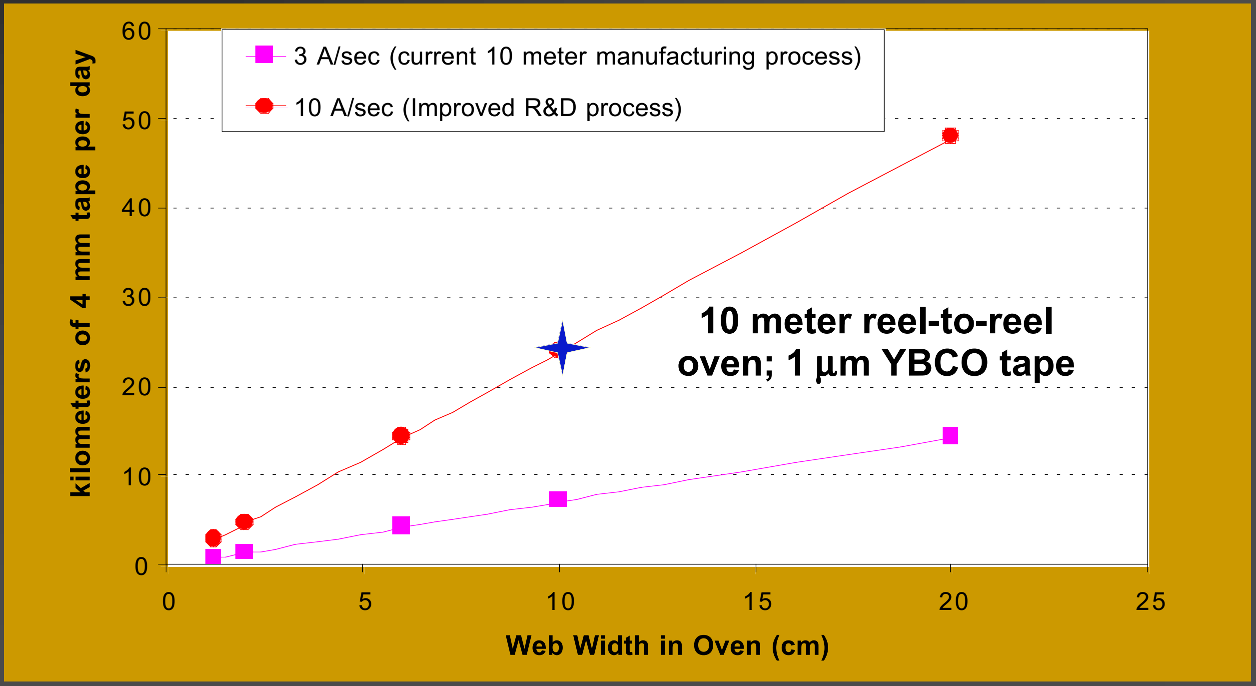
- Process by Metal Organic Deposition (MOD) YBCO
  - ✓ Single-crystal - CeO_2 / YSZ J_c(77K) = 4 MA/cm^2 @ t=0.8µm
  - ✓ Focus on RABiTS: CeO_2 / YSZ / Y_2O_3 / NiW substrate
  - ✓ 135 A/cm-width; J_c = 1.5 MA/cm^2 @ t = 0.8 µm (1-10 m lengths)
  - ✓ 200 A/cm-width; J_c = 2.2 MA/cm^2 @ t = 0.9 µm (short pieces)
  - ✓ 200 A/cm-width on both IBAD MgO and RABiTS
- MOD process optimization significantly improved
  - ✓ Growth rate = 10Å/s
  - ✓ Uniform reaction over length and width
  - ✓ Coating run limited substrate length
  - ✓ 100% material usage
  - ✓ J_c Thickness independent?



YBCO Deposition: Marty Rupich (AMSC)

- **Key step: Precursor Decomposition**
  - ✓ **Times reduced to less than 1 hour**
  - ✓ **10 m furnace can produce 0.25 km of web tape / day**
  - ✓ **10 cm wide web translates into 6.25 km of 4 mm wide conductor / day**
- **Key step: YBCO conversion**
  - ✓ **Depending on web width, km's of tape could be converted each day in a 10 m furnace.**
  - ✓ **Rates increased 10Å/sec**

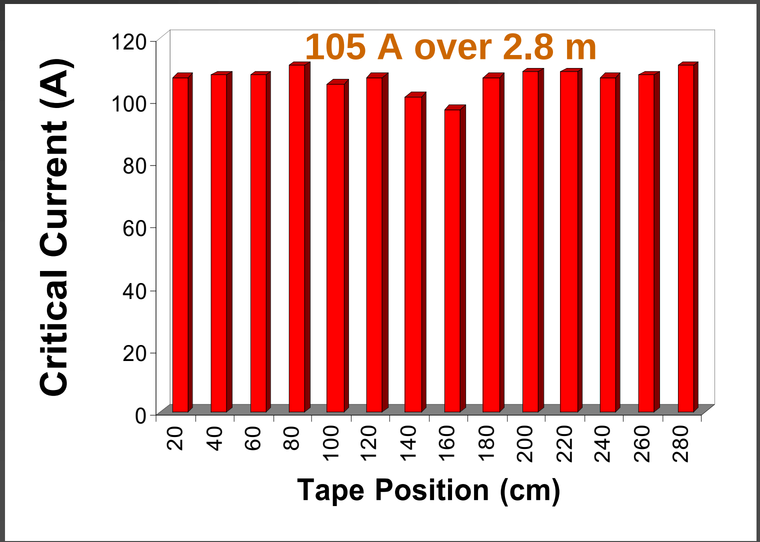
YBCO 4mm wide conductor production rates based on manufacturing and R&D YBCO conversion rates and the width of the web put through the furnace.



YBCO Deposition: Hee-Gyoun Lee (SuperPower)

- **MOCVD as a high rate deposition process for YBCO.**
  - ✓ **150Å/s deposition rates.**
  - ✓ **Deposition area limited only by showerhead size and furnace.**
  - ✓ **Double-side coatings are possible.**
- **Issues**
  - ✓ **Hardware failure during long runs (MOCVD amenable to restarts)**
  - ✓ **Process stability over long runs (MOCVD suitable for long lengths)**
  - ✓ **High critical currents in thick films (MOCVD High J_c films demonstrated)**

2.8 m length was limited by the section in the middle. Other sections had I_c's >> 100 A.

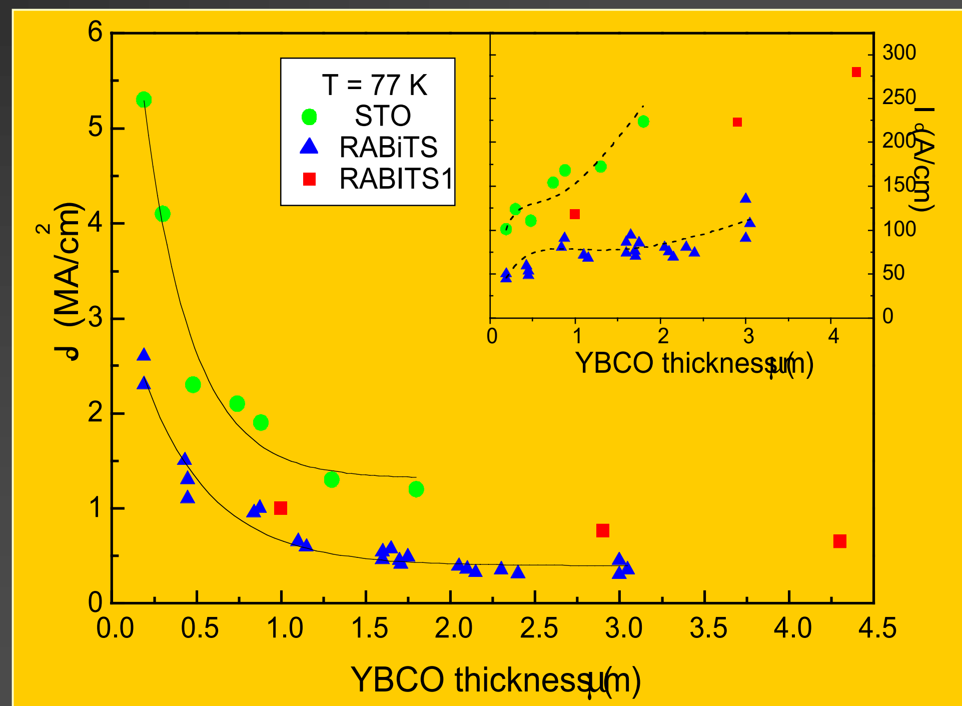


YBCO Deposition: Jim Voigt (SNL)

- **All solution deposition of buffer layers and YBCO**
  - ✓ **Low conductor materials cost \$0.39-0.78/kA-m**
  - ✓ **Linear speed 3cm/s - 950 km/y**
- **Obstacles to scale-up**
  - ✓ **Thickness of YBCO layers**
  - ✓ **Thick film conversion speed**
  - ✓ **Single-coat buffers with rapid thermal annealing**
- **Properties to date in short lengths (2.5-25 cm)**
  - ✓ **$LaAlO_3$: 4 MA/cm^2 - 100 A/cm-width - 0.25 µm YBCO**
  - ✓ **$LaAlO_3$: 0.7 MA/cm^2 - 91 A/cm-width - 1.3 µm YBCO (six layers)**
  - ✓ **STO/Ni: 1.3 MA/cm^2 - 16 A/cm-width - 0.12 µm YBCO**

YBCO Deposition: Amit Goyal (ORNL)

- **Primary mechanisms for J_c reduction with YBCO thickness vary significantly with substrate properties.**
  - ✓ **YBCO/STO: Growth of a-axis grains, broadening of the in-plane texture**
  - ✓ **YBCO/Ni: Degradation of % cube texture, formation of second phases, reaction with cap layer and formation of porosity**
  - ✓ **YBCO/NiW: Texture and microstructure quite intact even for a 6.4 mm YBCO film. Ni3%W(50µm) / Y_2O_3(150nm) / YSZ(150nm) / CeO_2(20nm) / YBCO 1-6.4 µm**
- **Suppressed a-axis growth in YBCO on NiW templates**
- **Demonstrated 280-350 A/cm-width on NiW templates and 4.3 µm thick YBCO film.**



Session V: Late Breaking News and Results

- **Steve Foltyn (LANL)** addressed the question of how good texture needs to be, a question that was frequently raised during the first day. He claimed that "single-crystal type" J_c values were obtained using IBAD MgO films that gave a FWHM of 2.7° for the in-plane texture of YBCO.
- **Paul Berdahl (LBNL)** described the ITEX (i.e., Ion Texturing) process, a simple, robust method for producing buffer layers.
- **David Shaw (SUNY-Buffalo)** described W_xN as a possible buffer layer, saying that it is a good oxygen diffusion barrier, has good electrical conductivity and good mechanical properties, and its lattice constant matches that of MgO. A question was raised regarding its chemical stability under YBCO deposition conditions.
- **Sankar Sambasivan (ATF, Inc.)** talked about the ECONO (i.e., Epitaxial Conversion to Oxide via Nitride Oxidation) process in which Y and Zr are deposited as a nitride that is then oxidized to form YSZ. He claimed that the process eliminates the need for a sulfur superstructure when working with a RABiTS substrate.
- **Winnie Wong-Ng (NIST)** is exploring the phase diagrams of various rare earth (RE)-123 compounds, for example, studying the solid solubility between them. Compositions in which Nd is substituted for Ba are of particular interest, because preliminary data show their J_c are higher than that of Y-123 at magnetic fields of 1-2 Tesla.

Session V: Late Breaking News and Results

- Larry Cook (NIST) discussed two areas of research. He is studying phase relations that may be important in processes that involve BaF_2, looking into the possibility that $Ba(OH)_2$ may play an important role through the formation of a liquid phase. He is also trying to sort out discrepancies in thermodynamic data for MgB_2 so that he can determine its thermal stability limit.
- Balu Balachandran (ANL) described two new directions for research in Japan. Self-epitaxy of CeO_2 on IBAD-$Gd_2Zr_2O_7$ films is being studied by Yamada at ISTEC-SRL; it has been used to obtain J_c of 3.8 MA/cm^2 at 77 K in self-field. Fujino at Sumitomo is investigating the use of Ho-123, because its deposition rate can be three times faster than that of Y-123.
- A common theme throughout the first day of the workshop was the dependence of I_c on the thickness of YBCO. Alex Gurevich (U. Wisc.-Madison) presented a model that he developed to describe this. He reported that the model fits Feldmann's experimental data of I_c through the thickness of a YBCO film.
- Sharmila Mukhopadhyay (Wright State U.) pointed out that the interfaces in coated conductors are poorly understood at present. She described work in which she is studying the phase relations at various interfaces to improve this understanding.
- Mas Suenaga (BNL) described a model for AC losses in coated conductors and pointed out that defects in the conductors influence the AC losses by disturbing the uniformity of magnetic fields in the conductor.

Session V: Late Breaking News and Results

- **Leonardo Civale (LANL) showed I_c for PLD-IBAD films in magnetic fields up to 18 Tesla. He showed that single and multilayer YBCO films have similar performances in magnetic fields with strengths >several Tesla. He also pointed out that decreasing temperature by ≈10 K can significantly alter the large drop in J_c that is typically seen at low magnetic fields (<0.5 Tesla).**
- **Paul Barnes (Air Force Research Lab.) described a technique in which he fabricates a multilayer structure that contains fine 211 inclusions. He showed that J_c for the multilayer films was ≈ 2 times higher than that of a single layer film at 1.5 Tesla.**
- **Mike Tomsic (Hyper Tech Research) described his capability to produce MgB_2 in both mono- and multi-filament configurations. He reported that, at 20 K, these conductors have a J_c up to 100 kA/cm^2 in self-field and a J_e of 15 kA/cm^2 in magnetic fields of 1-4 Tesla.**

Session VI: Rump Session Summary

- **Mechanical properties**
  - **+/- 0.25 strain roll direction**
  - **20 MPa perp. broad face**
  - **100 Mpa || broad face**
  - **Thick films may have added cyclic risk**
  - **Cabling hard way bend**
- **Issue - Getting 2G conductor into the hands of the application engineers.**

Dimensions for 2G "Conductors"

- 4 to 5 mm width
- I_c 100 to 200 A
- Thickness less of a driver
- High N-value is good for performance but makes protection of quench harder
- Issue - Machines are designed at about 1 microvolt/m

Special Properties for 2G Conductors

- **Cost is important**
- **Fault/recovery is challenging for current limiters and transformers**
- **More data of Critical current as a function of B, T, angle is needed**
- **AC losses: there is concern about ferromagnetic materials**
- **AC losses perpendicular to the broad face are of concern.**

Session VII: Characterization

- **Mechanical Properties - Jack Ekin (NIST)**
  - ✓ Handbook data for substrate materials are not be reliable because they are for random materials, not for highly textured materials.
  - ✓ The new, coated conductor geometry has a thick normal layer on top of the coated conductor. This puts the coated conductor at the neutral axis for bending. The strain – I_c relations need to be measured for this new geometry.
  - ✓ The coated conductor has a higher strain tolerance than BSCCO wire, so engineers should think out of the box when designing with coated conductors.

- **Raman Spectroscopy - Vic Maroni (ANL)**
  - ✓ Use micro-Raman spectroscopy to study coated conductors.
  - ✓ Technique identifies phases, phase separation, c-axis texture, cation mixing.
  - ✓ Used technique to study ex-situ BaF_2 tape from the beginning to the end of conversion and beyond (i.e., over converted) on a single piece of tape.
  - ✓ Can do reel-to-reel measurements
  - ✓ On-line diagnostic system could be built for $100,000.

Session VII: Characterization

- **X-ray Diffraction - Fred List (ORNL)**
  - ✓ Discussed three types of x-ray diffraction
  - ✓ Parallel beam x-ray diffraction – can move source and/or detector to do 2θ, φ, and ω scans
  - ✓ Divergent beam diffraction – can do φ, and ω scans without moving the source or detector
  - ✓ Energy dispersive diffraction – can do 2θ scans without moving the detector or source, but scan contains characteristic x-ray peaks from the elements in the sample

- **Long Length Electrical Measurements - Jeff Willis (LANL)**
  - ✓ End-to-end I_c measurements give good overview of tape, can localize problems to within 50cm or less, depending on the separation between voltage taps
  - ✓ Measuring highest Ic regions may burn out lowest I_c region – suppress high I_c region by applying a magnetic field.
  - ✓ Can use inductive and Hall probe measurements for long length tapes along and across the width of the tape.

Session VII: Characterization

- **In-situ Diagnostics -Vlad Matias (LANL)**
  - ✓ Discussed in-situ techniques to monitor process
  - ✓ Distinguished between monitoring a sample property (e.g. done using RHEED, FTIR) and process parameters (e.g. done using atomic absorption)
  - ✓ Distinguished between in situ monitoring (in-line) and in situ diagnostics (scientific study).
  - ✓ Want to have as many real-time in-situ monitors as possible to determine why something has gone wrong and potentially to correct the problem in real time.

- **TEM - Dean Miller (ANL)**
  - ✓ Ex-situ process
  - ✓ Currently making a TEM sample is a challenging, time consuming process. FIB (Focused Ion Beam) is just starting to be used to make TEM samples, which will speed up the sample making process immensely. Showed a movie of a FIB cutting a trench in an integrated circuit.
  - ✓ TEM data offer a richness of information not available from other techniques
  - ✓ Modern TEM's have capability of detecting many signals, high beam brightness, and high spatial resolution for structural and chemical information.

Session VIII: Role of Universities

- Support program goals: long lengths with good properties
- Apply to ongoing efforts at labs and in industry
- Provide new ideas and alternate directions
- Basic materials research including theory
- Detailed characterization at all length scales
- Support for application development?

Session VII: Role of Universities

- **Larbalestier/UW**
  - ✓ Capability: wide range of film growth tools, characterization, and theoretical support
  - ✓ Studies of J_c vs. thickness, both materials and physics issues
  - ✓ Model film growth systems using high pressure RHEED
  - ✓ Implementation of aerosol spray pyrolysis for entire stack
- **Hammond/Stanford**
  - ✓ Understand high rate in situ growth processes
  - ✓ YBCO phase stability (role of liquid phases)
  - ✓ Issues: confirm high J_c with high rate, thickness dependence, extend to metal tapes
  - ✓ Sensors for process control

Session VII: Role of Universities

- **Cima/MIT**
  - Problems: low growth rate of c-axis oriented, J_c decrease with film thickness,
  - For TFA precursors, rapid thermal anneal can achieve conversion rates greater than 6 nm/sec on RABiTS under low pressure
  - F/Ba ratio may play central role

- **Thompson/UT**
  - Basic ferromagnetic properties of Ni based alloys
  - Dependence of Curie T_c and M_{sat} on alloying
  - Focus on hysteretic losses both in substrate and HTSC, these scale very differently with current

Session VII: Role of Universities

- **Haldar/U. Albany**
  - **Capabilities of Albany NanoTech:**
    - **300 mm wafer prototyping in fall ’03**
    - **Advanced characterization tools including FIB, RBS**
    - **Modeling and processing tools for a wide range of deposition techniques**

- **Schwartz & Iwasa/Florida State & MIT**
  - **Understand normal zone creation/propagation**
  - **Can now measure quench energies and propagation velocities**
  - **Find NZPV is slow at 81K**

Workshop Issues: Looking Forward

- **Scale-up of RABiTS, IBAD or ISD**
  - ✓ Are reliable lengths of the templates available for effective scale-up?
  - ✓ What is the functionality combining both in-plane and out-of-plane misalignment and the limitations on J_c?
  - ✓ What are the costs of RABiTS, IBAD, or ISD substrates?
- **What are the basic drivers for buffer layer development?**
  - ✓ Diffusion coefficients - Do we know what they are?
  - ✓ Diffusion mechanisms - How do cations / anions move about the composite during processing.
  - ✓ What is special about CeO_2 that makes it the predominant choice for the final cap layer? (Other than it works!)
  - ✓ Costs?
- **What is the optimal thickness of the YBCO layer?**
  - ✓ 1-2.5 µm/high J_c vs. 2.5 - ? µm/ intermediate J_c
  - ✓ Mechanical properties of thick YBCO films?
  - ✓ What about double-sided composites?
  - ✓ How are the YBCO layers stabilized?
  - ✓ Is YBCO deposition the slowest step of the process?

Workshop Issues: Looking Forward

- **How do we close the gap between the application development and processing groups?**
  - **More conductor lengths to development teams.**
  - **Co-location of development personnel with Accelerated Coated Conductor Initiatives or Industry wire manufacturers?**
  - **More University involvement in application development issues?**
    - **Mechanical properties**
    - **Conductor characterization**
    - **Cryogenics issues**
- **How do we better integrate the characterization capabilities of the DOE Laboratories and Universities with conductor processing and application development programs?**
- **What strategic role(s) can the Universities play in Coated Conductor and Application Development?**
  - **Basic research into theory / new processes / materials / advanced characterization?**
  - **Students for future growth in HTS industry?**
  - **Professor / Student "sabbaticals" with DOE labs or industry?**